List of Equations (only some of these equations are required to solve question 3 and 4)

Power delivered to the load	$P_L = \frac{\lvert V_2^- \rvert^2}{2Z_0}\left(1 - \lvert \Gamma_L \rvert^2\right)$
Input power to the network	$P_{in} = \frac{\lvert V_1^+ \rvert^2}{2Z_0}\left(1 - \lvert \Gamma_{in} \rvert^2\right)$
Input and output reflection coefficients of a transistor with a source and load: general case	$\Gamma_{in} = \frac{V_1^-}{V_1^+} = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L}$ $\Gamma_{out} = \frac{V_2^-}{V_2^+} = S_{22} + \frac{S_{12}S_{21}\Gamma_S}{1 - S_{11}\Gamma_S}$
Input and output reflection coefficients of a transistor with a source and load: unilateral case	$\Gamma_{in} = \frac{V_1^-}{V_1^+} = S_{11}$ $\Gamma_{out} = \frac{V_2^-}{V_2^+} = S_{22}$
Gain of the input matching network	$G_S = \frac{1 - \lvert \Gamma_S \rvert^2}{\lvert 1 - \Gamma_{\text{in}}\Gamma_S \rvert^2}$
Gain of the output matching network	$G_L = \frac{1 - \lvert \Gamma_L \rvert^2}{\lvert 1 - S_{22}\Gamma_L \rvert^2}$
Gain of the transistor (unilateral case)	$G_0 = \lvert S_{21} \rvert^2$
Transducer gain of the basic amplifier circuit (input matching, unilateral transistor, output matching)	$G_T = G_S G_0 G_L$ $G_{T,dB} = G_{S,dB} + G_{0,dB} + G_{L,dB}$
Maximum gain of the input and output matching networks	$G_{S_{\max}} = \frac{1}{1 - \lvert S_{11} \rvert^2},$ $G_{L_{\max}} = \frac{1}{1 - \lvert S_{22} \rvert^2}.$
Maximum transducer power gain, unilateral case	$G_{TU_{\max}} = \frac{1}{1 - \lvert S_{11} \rvert^2}\lvert S_{21} \rvert^2 \frac{1}{1 - \lvert S_{22} \rvert^2}$
Normalized gain factors g_s and g_L	$g_S = \frac{G_S}{G_{S_{\max}}} = \frac{1 - \lvert \Gamma_S \rvert^2}{\lvert 1 - S_{11}\Gamma_S \rvert^2}(1 - \lvert S_{11} \rvert^2),$ $g_L = \frac{G_L}{G_{L_{\max}}} = \frac{1 - \lvert \Gamma_L \rvert^2}{\lvert 1 - S_{22}\Gamma_L \rvert^2}(1 - \lvert S_{22} \rvert^2).$
Center and radius of the constant gain circle for the input matching network	$C_S = \frac{g_S S_{11}^*}{1 - (1 - g_S)\lvert S_{11} \rvert^2},$ $R_S = \frac{\sqrt{1 - g_S}\,(1 - \lvert S_{11} \rvert^2)}{1 - (1 - g_S)\lvert S_{11} \rvert^2}$
Center and radius of the constant gain circle for the output matching network	$C_L = \frac{g_L S_{22}^*}{1 - (1 - g_L)\lvert S_{22} \rvert^2},$ $R_L = \frac{\sqrt{1 - g_L}\,(1 - \lvert S_{22} \rvert^2)}{1 - (1 - g_L)\lvert S_{22} \rvert^2}$

Condition for "unconditionally stable" device, general case	for all $\lvert\underline{\Gamma}_L\rvert<1$ and $\lvert\underline{\Gamma}_S\rvert<1$ $\Rightarrow \begin{cases} \lvert\Gamma_{in}\rvert = \left\lvert S_{11}+\dfrac{S_{12}S_{21}\Gamma_L}{1-S_{22}\Gamma_L}\right\rvert < 1 \\ \lvert\Gamma_{out}\rvert = \left\lvert S_{22}+\dfrac{S_{12}S_{21}\Gamma_S}{1-S_{11}\Gamma_S}\right\rvert < 1 \end{cases}$
Conditions for "unconditionally stable" device, unilateral case	$\lvert\Gamma_{in}\rvert = \lvert S_{11}\rvert < 1$ $\lvert\Gamma_{out}\rvert = \lvert S_{22}\rvert < 1$
Center and radius of the stability circles, load side	$C_L = \dfrac{(S_{22}-\Delta S_{11}^{*})^{*}}{\lvert S_{22}\rvert^2-\lvert\Delta\rvert^2}$ (center), $R_L = \left\lvert\dfrac{S_{12}S_{21}}{\lvert S_{22}\rvert^2-\lvert\Delta\rvert^2}\right\rvert$ (radius). $\Delta = S_{11}S_{22} - S_{12}S_{21}$
Center and radius of the stability circles, source side	$C_S = \dfrac{(S_{11}-\Delta S_{22}^{*})^{*}}{\lvert S_{11}\rvert^2-\lvert\Delta\rvert^2}$ (center), $R_S = \left\lvert\dfrac{S_{12}S_{21}}{\lvert S_{11}\rvert^2-\lvert\Delta\rvert^2}\right\rvert$ (radius) $\Delta = S_{11}S_{22} - S_{12}S_{21}$
Test for unconditional stability, general case	$\lvert\Delta\rvert = \lvert S_{11}S_{22}-S_{12}S_{21}\rvert < 1$ **and** $K = \dfrac{1-\lvert S_{11}\rvert^2-\lvert S_{22}\rvert^2+\Delta^2}{2\lvert S_{12}S_{21}\rvert} > 1$
Test for unconditional stability, unilateral case	$\lvert S_{11}\rvert < 1$ $\lvert S_{22}\rvert < 1$
Noise figure of a 2-port amplifier	$F = F_{\min} + \dfrac{r_N}{g_S}\lvert\underline{y}_S-\underline{y}_{opt}\rvert^2$ $F = F_{\min} + 4r_N\dfrac{\lvert\underline{\Gamma}_S-\underline{\Gamma}_{opt}\rvert^2}{\left(1-\lvert\underline{\Gamma}_S\rvert^2\right)\cdot\lvert 1+\underline{\Gamma}_{opt}\rvert^2}$
Constant noise circles	$\underline{C}_F = \dfrac{\Gamma_{opt}}{1+N}$ $R_F = \dfrac{1}{1+N}\sqrt{N^2+N(1-\lvert\Gamma_{opt}\rvert^2)}$ $F_{min} = 10^{\frac{NF_{min}}{10}}$ $\Delta F_n' = N = \left(F-F_{\min}\right)\dfrac{\lvert 1+\underline{\Gamma}_{opt}\rvert^2}{4r_n} = \dfrac{\lvert\underline{\Gamma}_S-\underline{\Gamma}_{opt}\rvert^2}{1-\lvert\underline{\Gamma}_S\rvert^2}$

Output noise, input noise, equivalent noise temperature, noise factor and noise figure	$N_o = Gk_B(T_0 + T_e)B$ $N_i = k_B T_0 B$ $F = \frac{\frac{S_i}{N_i}}{\frac{S_o}{N_o}} = \frac{S_i}{S_o}\frac{N_o}{N_i} = \frac{1}{G}\frac{Gk_B(T_0 + T_e)B}{k_B T_0 B} = 1 + \frac{T_e}{T_0}$ $NF = 10\log_{10} F$
Three-stage amplifier: **Output noise ($P_{n,total}$), noise factor (F_{total}) noise figure (NF_{total})**	$P_{n,total} = G_{A3}G_{A2}G_{A1}P_{n,in} + G_{A3}G_{A2}P_{n1} + G_{A3}P_{n2} + P_{n3}$ $F_{total} = \frac{P_{n,total}}{G_{A3}G_{A2}G_{A1}P_{n,in}}$ $F_{total} = 1 + \frac{P_{n1}}{G_{A1}P_{n,in}} + \frac{P_{n2}}{G_{A1}G_{A2}P_{n,in}} + \frac{P_{n3}}{G_{A3}G_{A2}G_{A1}P_{n,in}}$ $F_{total} = F_1 + \frac{F_2 - 1}{G_{A1}} + \frac{F_3 - 1}{G_{A1}G_{A2}}$ $NF_{total} = 10\log_{10} F_{total}$ Noise factor of single stage $F_j = 1 + \frac{P_{nj}}{G_{Aj}P_{n,in}}, j = 1,2,3$ Noise figure of single stage $NF_j = 10\log_{10} F_j\ , j = 1,2,3$
Receiver sensitivity	$P_{sens}\ [dBm] = k_B T_0 B[dBm] + NF_{total}[dB] + SNR[dB]$ $P_{sens}\ [dBm] = -174 + NF_{total} + 10\log_{10} B + SNR$ $k_B - \text{Boltzman constant}, k_B = 1.38 \cdot 10^{-23}\frac{Watt \cdot s}{K}$
Conversion Watt to dBm	$P_{sens}\ [dBm] = 10\log_{10}\frac{P_{sens}\ [Watt]}{1mWatt}$ $P_{sens}\ [dBm] = 10\log_{10}\frac{P_{sens}\ [Watt]}{10^{-3}Watt}$
Gain conversion from linear to dB	$G\ [dB] = 10\log_{10} G$
Friis radio link formula	$P_{RX} = P_{TX}G_{TX}G_{RX}(\frac{\lambda}{4\pi R})^2$ P_{RX} – power at RX input P_{TX} – power at TX output G_{RX} – RX antenna gain G_{TX} – TX antenna gain λ – wave length $\lambda = \frac{c}{f}$ $c - speed\ of\ light, c = 3 \cdot 10^8\frac{m}{s}$ f – frequency